WHAT COLOUR is YOUR BUILDING?

Measuring and reducing the energy and carbon footprint of buildings

David H. Clark

Appendix E

Embodied carbon data

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Appendix E: Embodied carbon data

Infinite growth of material consumption in a finite world is an impossibility.
E. F. Schumacher, Economist.

Contents

This appendix provides additional information and data to support Chapter 3 (Embodied carbon).

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E1. ECO_2 FACTORS FOR MATERIALS

There are many sources of coefficients for embodied energy and carbon of materials including manufacturing industry data, Life Cycle Assessment software databases and research databases. One of the most commonly used sources in the UK is *Embodied Carbon – The Inventory of Carbon and Energy (ICE)*,[1] published by the University of Bath. The inventory is free to download and the accompanying guide can be purchased from BSRIA. The inventory was created to provide a freely available and robust source of data for materials used in the construction process in the UK. Version 2 (2011) covers 34 materials, including aggregates, aluminium, cement, bricks, concrete, glass, plastics, steel and timber.

The data was collated from various sources, assessed and rated for quality, from which the appropriate coefficients could be derived for cradle-to-gate. A key strength is the transparency of the data sources, including notes on uncertainties in values (typically ±30%). The accompanying BSRIA guide provides worked examples, case studies and information about embodied energy and carbon in buildings.

As discussed in Chapter 3, estimating embodied carbon is very similar to estimating life cycle costs. Table E.1 shows a comparison between estimating costs and embodied carbon.

	ISO 15978 modules		Cost	Embodied carbon (ECO_2)
Construction	A	Materials	Quantity x £/unit	Quantity x $kgCO_2e$/unit
		Construction activities	Preliminaries (%)	Allowance (%) for, or calculation of, transport, site energy and waste
		Uncertainty	Design and construction risk contingency (%)	Allowance for unknowns
Operation	B	Maintenance	Replacement / repair costs for elements	Similar to above
Disposal	C & D	End of life	Demolition and waste disposal	Allowance for demolition works $kgCO_2e$ for whether material is reused, recycled or sent to landfill

Table E.1 **Cost and carbon at different life cycle stages**

Due to the similarities in the process, it is not surprising that a number of cost estimating books now include ECO_2 factors alongside the unit cost rates. For example, the *CESMM3 – Carbon & Price Book 2011*, edited by Franklin + Andrews and published by the Institution of Civil Engineers, has over 600 pages providing these for civil engineering and building works. When a bill of quantities is developed, the embodied carbon (cradle-to-gate) can also be estimated by the addition of an extra column to the spreadsheet. The authors of CESMM3 have 'developed their own estimates of embodied CO_2 data for materials' using a variety of sources, including the Inventory of Carbon and Energy.

Various industry publications also contain embodied carbon values. *The Whole Story: From Cradle to Grave*, published by Building magazine in association with the UK steel industry in early 2012, listed the embodied carbon of common construction materials used in the Target Zero building studies.[2]

A selection of values from the three sources above are summarised in Table E.2.

Material	Unit	$kgCO_2e$ / unit		
		ICE v2	CESMM3	Target Zero
Steel section	t	1530 [(a)] *(750 - substitution)* *(1140 - 50:50)*	2107	1009
35/40 MPa concrete [(b)]	m^3	367	419 [(c)] *(380)*	375
Steel reinforcement	t	770 [(d)]	1710	820
102.5mm clay brick wall	m^2	49 [(e)]	97	-

(a) The ICE v2 factor is based on the UK/EU average of 59% recycled content and takes the benefit of the recycled content. The substitution method takes the benefit of recyclability of steel at the end of life, and the 50:50 method assumes a mix of both.
(b) Typical in situ concrete mix in the UK assuming 25% ggbs cement substitution.
(c) Value for 20 mm aggregate (40 mm aggregate in brackets).
(d) Calculated based on 0.077 $kgCO_2e/kg$ for each 100 kg of reinforcement per m^3 of concrete.
(e) The ICE database notes a variation of a factor of 10 between low and high estimates of embodied energy.

Table E.2 Comparison of structural material cradle-to-gate carbon coefficients

There appears to be a reasonable degree of consistency in the ECO_2 factors for concrete, however the diversity of ECO_2 factors for steel is quite substantial. Consequently, the factors chosen will have a significant impact on the results of an embodied carbon assessment, particularly if trying to justify one material over another. Embodied carbon values for buildings should really be expressed as a range, rather than an absolute value, to reflect the wide variation and uncertainty in the data available. The steel versus concrete building debate is discussed in Chapter 8 and Appendix J.

The ECO_2 factors given in Chapter 8 for different materials have been taken from the Inventory of Carbon and Energy (unless otherwise noted) for three reasons:

- it is free
- it is widely referenced in numerous embodied carbon studies
- it transparently reports the data sources, highlighting assumptions and providing guidance on the uncertainty of the data.

DIFFERENCES IN SOFTWARE ANALYSIS RESULTS

A study on the standards and software tools by Howard Darby of Reading University in 2011 found a lack of a standardised approach to the calculation of embodied energy and of reliable data on emission factors for building materials and processes.[3] The analysis was based on an 11,578 m^2 steel framed book storage building in Swindon, housing a mix of offices and stores. The building (ignoring furniture and fittings) was run through the simulation packages CES Eco-selector, EA Carbon Calculator (a free online package) and BRE's Envest 2. The values were up to 40% lower than Darby's manual calculations. 'Different assumptions and boundary conditions can produce widely differing results', said Darby, 'and confirms the need for standardisation of embodied carbon data and assessment methods.' Software tools should be treated with caution, and sanity checks should be undertaken to test the outputs.

E2. CALCULATING THE EMBODIED CARBON OF AN ELEMENT

The carbon data for materials is used to build up the embodied carbon of elements within a building, to allow comparison of different design options. This takes into account the specification and quantities of each material. Figure E.1 shows the typical materials in a composite suspended floor slab. Calculating the embodied carbon requires the mass (or volume) of each material to be determined and then multiplied by the relevant ECO_2 factor.

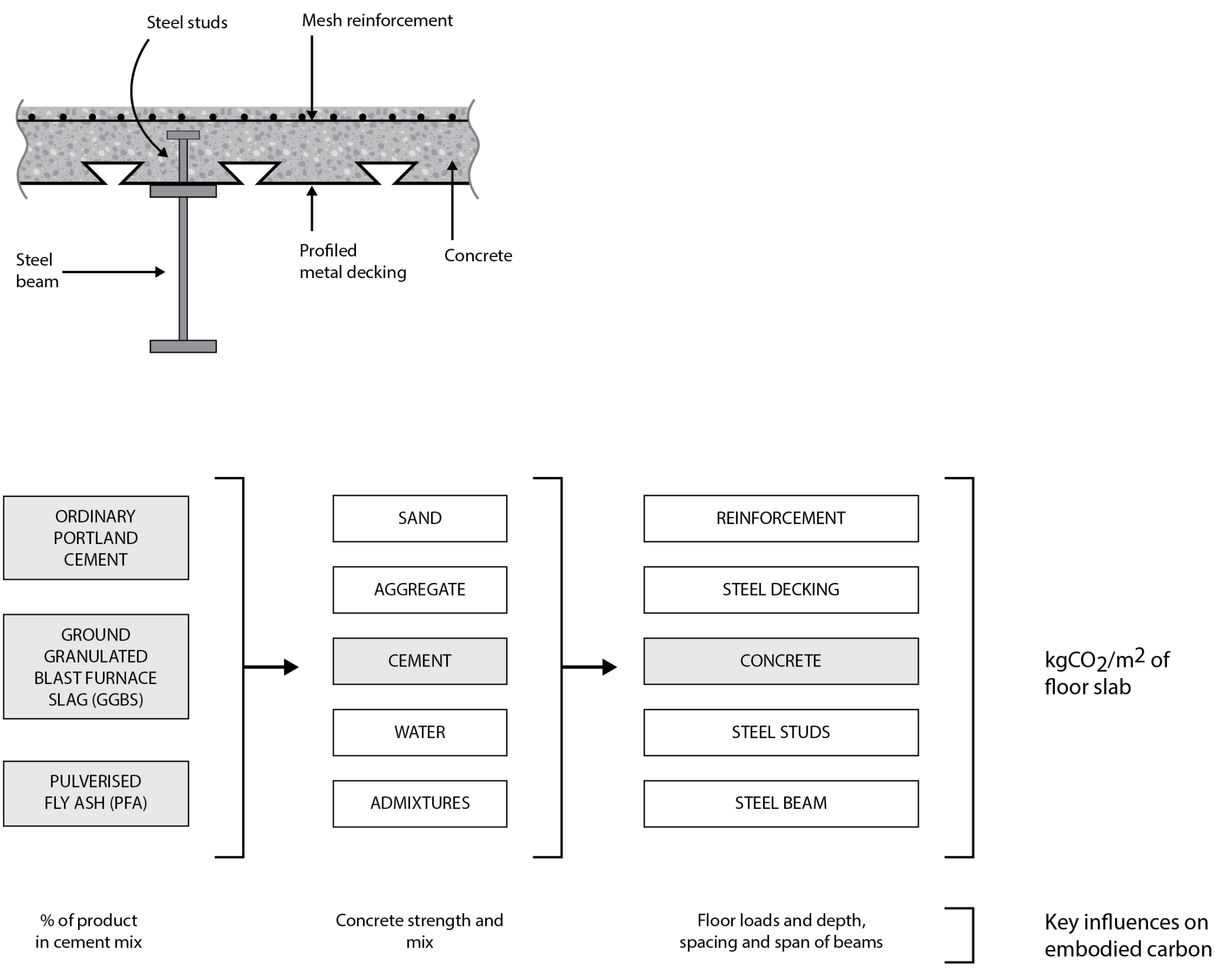


Fig E.1 **Key materials build up in a composite floor slab**

The embodied carbon per m^2 for the floor will vary depending on the type of concrete used and the emissions factors assumed for each component. The carbon emissions due to delivery to site and construction activities are then added to this ‘cradle to gate’ value to give a ‘cradle to site’ value.

E3. FIT-OUT EMBODIED CARBON USING THE INPUT-OUTPUT METHODOLOGY

Since all products or services have a carbon footprint, a crude estimate of carbon emissions can be obtained if the cost of the product or services is known using an input-output model. The book *How Bad Are Bananas?* by Mike Berners-Lee[4] contains a table of the 'Carbon Footprint of UK services and products from different industries per £ of value based on 2009 prices'. For example, spending £1 on furniture releases 0.66 kgCO_2e, £1 on carpets releases 0.39 kgCO_2e and £1 on construction releases 0.38 kgCO_2e.

If the cost of a Cat B fit-out is between £500/m^2 and £1,250/m^2 of NLA, and assuming 25% due to furniture and an NLA to GIA ratio of 1.25, this gives an estimated carbon footprint of between 180 and 450 kgCO_2e/m^2 of GIA using the factors above.

To test whether this methodology is likely to be realistic, consider the construction of an office building. If the typical construction cost varies between £1,500/m^2 and £2,500/m^2, then this gives a range of 570 to 900 kgCO_2e/m^2, which is reasonably consistent with the values in Figure 3.7 in Chapter 3.

E4. EMBODIED CARBON AT END OF LIFE

Chapter 3 briefly discussed the problems of determining what happens to materials at the end of their life, and how they are treated in a carbon footprint calculation.

Currently, the construction industry is responsible for around one third of the waste generated in the UK, the largest contribution from any sector. In 2010, 47.4 million tonnes (mt) of waste was produced in the UK from construction and demolition activities (excluding excavation), down from 58 mt in 2008.[5] Of this, 34.8 mt (73%) was used as aggregate, 7.2 mt (15%) was sent to waste transfer / treatment centres, and 5.3 mt (12%) ended up on landfill. The percentage of waste being sent to landfill is reducing each year, due to an increase in waste management education, recycling processes and landfill taxes.

In the CEN/TC 350 standards,[6] the disposal of demolition waste is covered by Module C (end of life stage) – refer to Figure 3.6 in Chapter 3. If the waste is then used by another process or industry once it has been disposed of (e.g. reused, recycled or converted to energy) then this is outside the building life cycle boundary and is covered in Module D.

It is very difficult to predict what the normal demolition, recycling and waste disposal practices will be at the end of a building's life, although it is probably fair to assume that in 60 years time the construction industry will be a lot better at diverting waste from landfill and making good use of it. This is why this component of the life cycle carbon is so open to interpretation, and why Module D has to be considered separately to the life cycle assessment of buildings. Chapter 8 discusses how the different end of life assumptions have a significant impact on the whole life carbon estimates of steel and timber in particular.

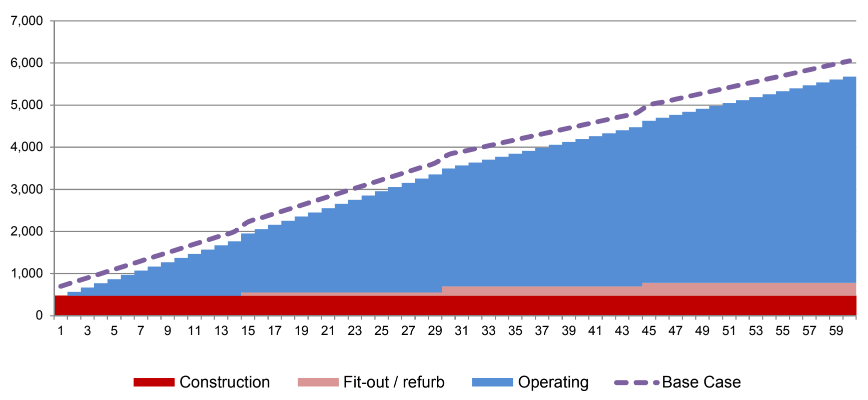
E5. EMBODIED VERSUS OPERATING CARBON SCENARIOS

Figures 3.11 and 3.12 in Chapter 3 were based on various scenarios which were summarised in Table 3.6. This section provides further details, data and graphs for each of these scenarios.

E5.1 High and low embodied carbon

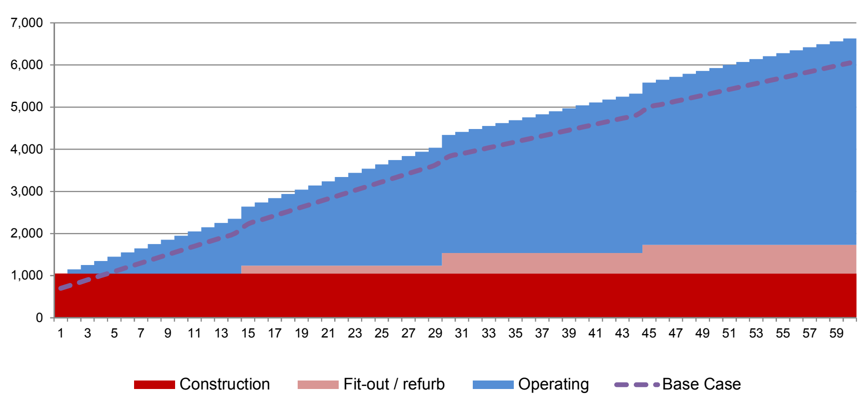
This scenario (shown in Figure E.2) varied the embodied carbon values for initial construction, fit-out and refurbishment, using the high and low values from Table 3.4. The lower value for initial construction of 470 $kgCO_2e/m^2$ is lower than most of the case studies in Figure 3.7, while the upper value of 1050 $kgCO_2e/m^2$ is higher than most of the examples.

1a. Low embodied carbon (33% less than base case)



	$kgCO_2e/m^2$	%
Initial construction	470	8%
Fit-out and refurb	310	6%
Operating energy	4,900	86%
TOTAL	**5,680**	
Change compared to base case		*-6%*

1b. High embodied carbon (50% greater than base case)



	$kgCO_2e/m^2$	%
Initial construction	1,050	16%
Fit-out and refurb	680	10%
Operating energy	4,900	74%
TOTAL	**6,630**	
Change compared to base case		*+10%*

Fig E.2 **60 year CO_2e emissions for high and low embodied carbon scenarios**

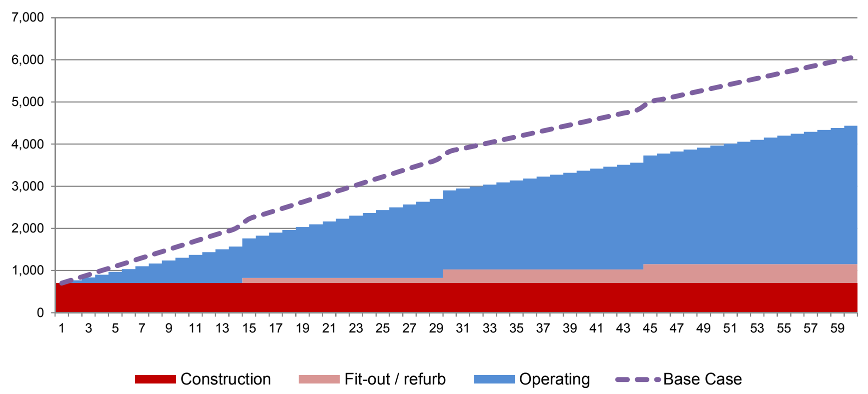
E5.2 High and low operating carbon

This scenario (shown in Figure E.3) considered different values for annual operating energy consumption as shown in Table E.3:

	Change compared to base case	$kgCO_2e/m^2$ of GIA per year	
		Years 1 to 30	Years 31 to 60
Base case	-	100	70
Low energy consumption	- 33%	67	47
High energy consumption	+ 50%	150	105

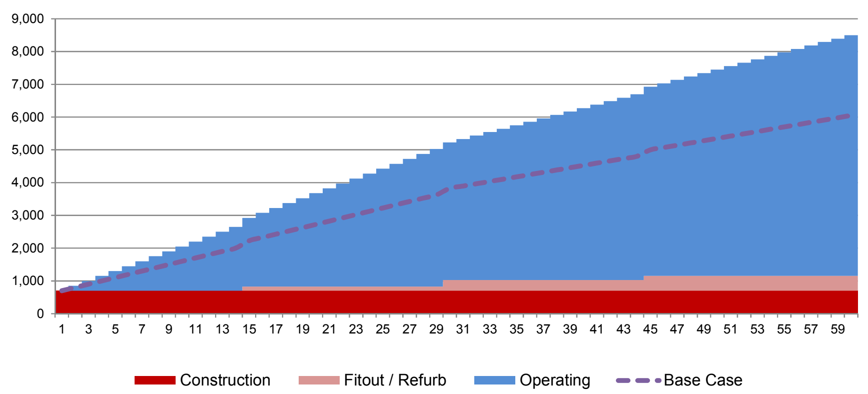
Table E.3 High and low operating carbon assumptions

2a. Low operating carbon (33% less than base case)



	$kgCO_2e/m^2$	%
Initial construction	700	16%
Fit-out and refurb	450	10%
Operating energy	3,283	74%
TOTAL	**4,433**	
Change compared to base case		*-27%*

2b. High operating carbon (50% greater than base case)



	$kgCO_2e/m^2$	%
Initial construction	700	8%
Fit-out and refurb	450	5%
Operating energy	7,350	86%
TOTAL	**8,500**	
Change compared to base case		*+40%*

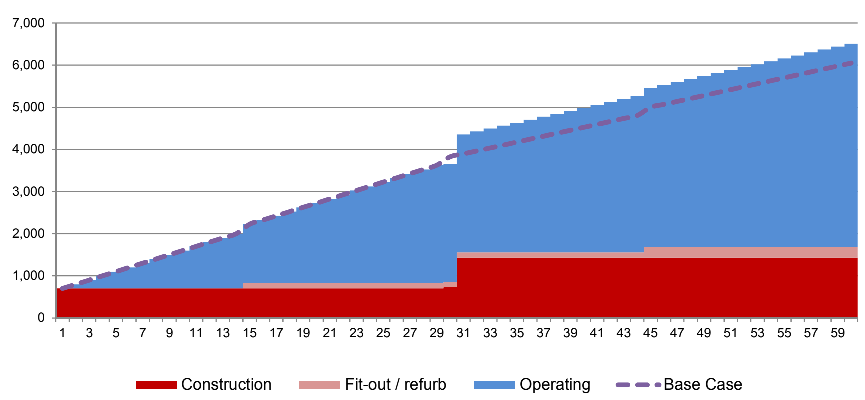
Fig E.3 60 year CO_2e emissions for high and low operating carbon scenarios

E5.3 Reduced life span

This scenario (shown in Figure E.4) assumed that the building was demolished after 30 years and replaced with a new office building of an identical size. Two options were considered:

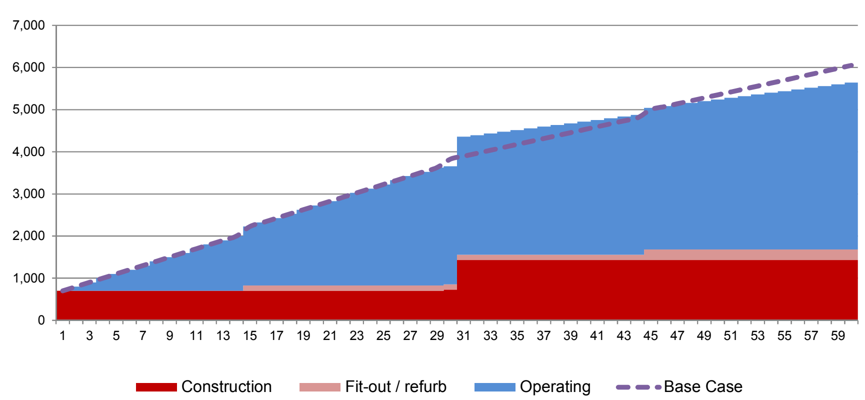
- The new building has an energy consumption of 70 $kgCO_2e/m^2$ (the same as the base case building following the major refurbishment after 30 years).
- The new building has an energy consumption of 40 $kgCO_2e/m^2$, which is 60% more efficient than the original building (100 $kgCO_2e/m^2$). This assumes much more stringent energy efficiency standards for new buildings in the future.

3a. Operating energy same as base case after rebuild (70 $kgCO_2e/m^2$)



	$kgCO_2e/m^2$	%
Initial construction	1,430	22%
Fit-out and refurb	250	4%
Operating energy	4,830	74%
TOTAL	**6,510**	
Change compared to base case		*+8%*

3b. Operating energy lower after rebuild (40 $kgCO_2e/m^2$)



	$kgCO_2e/m^2$	%
Initial construction	1,430	25%
Fit-out and refurb	250	5%
Operating energy	3,960	70%
TOTAL	**5,640**	
Change compared to base case		*-7%*

Fig E.4 60 year CO_2e emissions for reduced life span of building options

E5.4 Grid decarbonisation

The previous scenarios all assume that the operating CO_2e emission factors and the ECO_2 factors are the same in year 60 as in year 1. The reality is that legislation and energy policy will drive reductions in the CO_2e emissions of grid electricity and transport fuels in the future.

The UK's carbon target is an 80% reduction in the country's total CO_2 by 2050,[7] a period of less than 40 years. Much of this will need to be achieved by reducing the CO_2 emissions associated with producing electricity, although manufacturing and transport sectors (which both contribute to embodied carbon) will also need to reduce. The UK Government's Committee for Climate Change has proposed a 95% cut in grid electricity emissions by 2050, in order to achieve the overall 80% carbon reduction target.[8] The UK Government will not set a formal grid decarbonisation target until 2016.

To test the potential impact of grid decarbonisation on the carbon footprint of buildings, two scenarios have been considered (as shown in Figure E.5):

- 80% by 2050 and 90% by 2070 for 'Best Case' scenario.
- 45% by 2050 and 75% by 2070 for 'Political Reality' scenario.

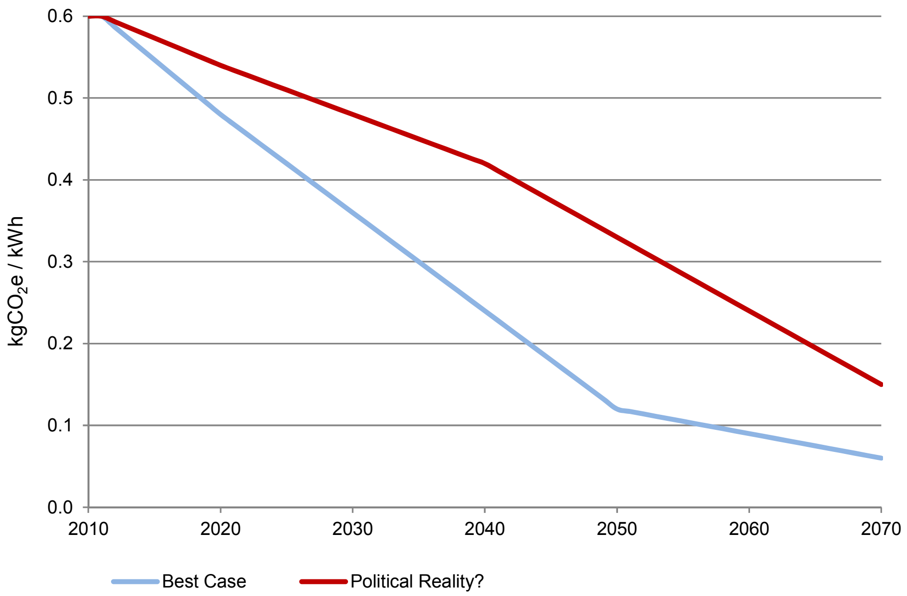


Fig E.5 **Two potential scenarios for decarbonisation of UK grid electricity over 60 years (2010 to 2070)**

The operating carbon of the building in year 1 (100 $kgCO_2e/m^2$) is assumed to comprise 85% grid electricity and 15% gas. The grid decarbonisation factors are only applied to the electricity component. For example, in 2030 the grid electricity factor for the best case scenario is 0.36 $kgCO_2e/kWh$, a reduction of 40% compared to 0.6 $kgCO_2e/kWh$ in 2010.

$$\text{Operating energy in 2030} = 100\ kgCO_2e/m^2 \times (1 - 85\% \times 40\%) = 66\ kgCO_2e/m^2$$

Grid electricity is also used in the production of materials. Assuming grid electricity accounts for 30% of embodied carbon in buildings, the same reducing emission factors can be applied to this proportion of the embodied carbon of fit-out and refurbishment when they occur during the 60 year assessment period.

Government carbon reduction policy, now and in the future, will not be limited to grid electricity, and measures to reduce transportation and manufacturing emissions in order to meet carbon targets are likely. These will reduce the embodied carbon of materials in the future. To make an estimate of this impact, the remaining 70% of embodied carbon values are assumed to reduce in a similar timescale to grid electricity, but at a rate of one third of the reduction of the electricity grid.

Applying these assumptions, the reduction in the embodied carbon value for 2050 under the best case scenario would be [30% x 80% + 70% x 80% x 30%] = 41%. Figure E.6 shows the assumed decarbonisation reductions to be applied to the operating and embodied carbon factors.

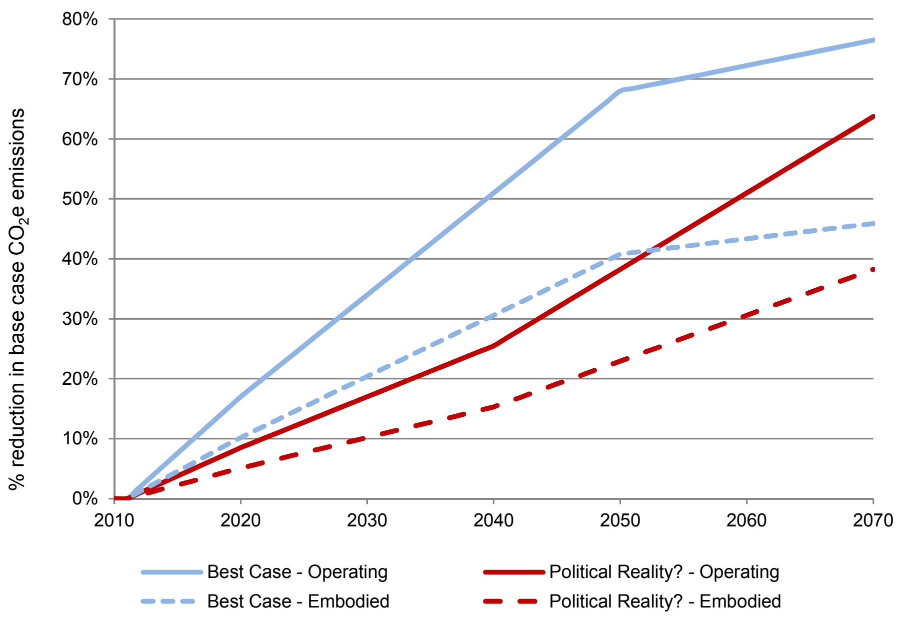
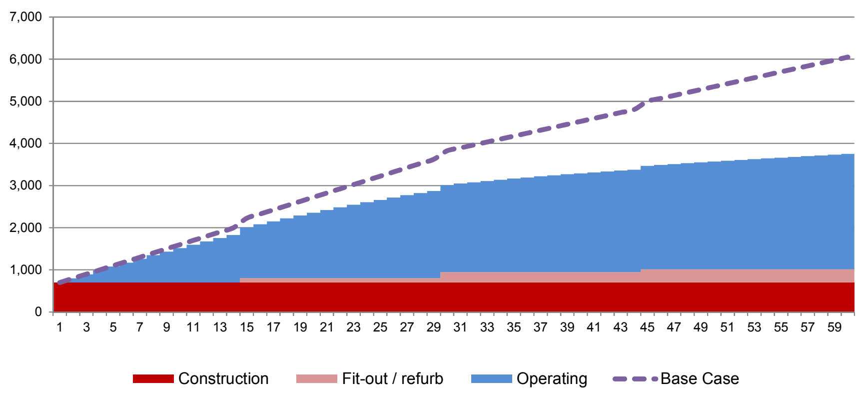


Fig E.6 **Reduction factors for embodied and operating carbon due to decarbonisation scenarios**

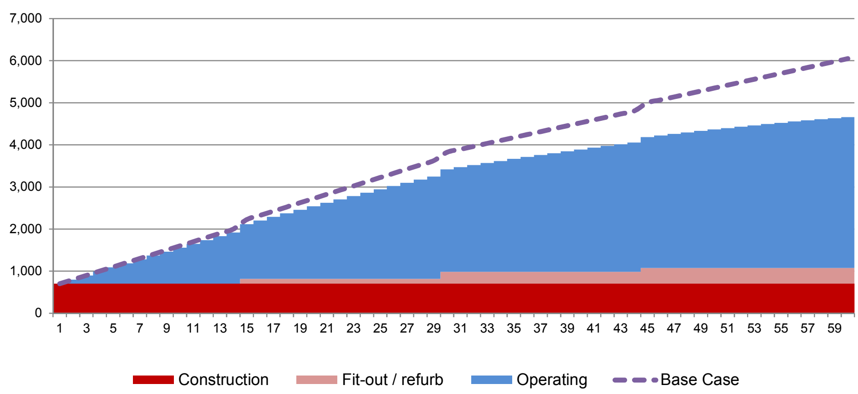
Figure E.7 shows the results of applying these to the base case building, assuming construction in 2010.

4a. Best case decarbonisation



	$kgCO_2e/m^2$	%
Initial construction	700	19%
Fit-out and refurb	317	8%
Operating energy	2,732	73%
TOTAL	**3,749**	
Change compared to base case		*-38%*

4b. Political reality decarbonisation



	$kgCO_2e/m^2$	%
Initial construction	700	15%
Fit-out and refurb	376	8%
Operating energy	3,584	77%
TOTAL	**4,660**	
Change compared to base case		*-23%*

Fig E.7 60 year CO_2e emissions for grid decarbonisation options

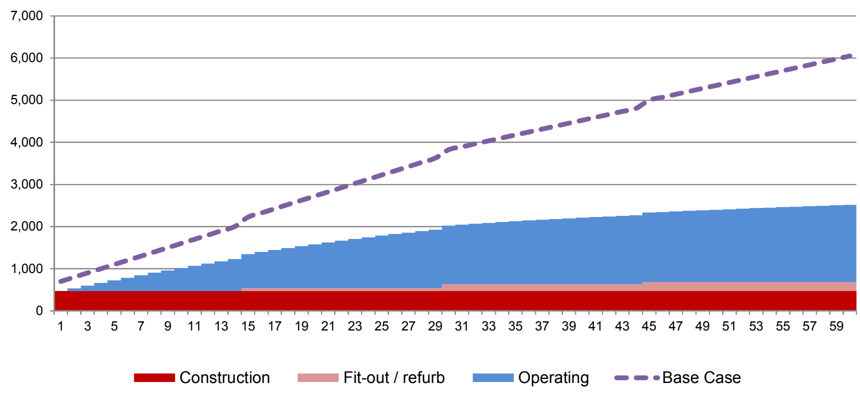
E5.5 Upper and lower limits (including grid decarbonisation)

The upper and lower limit scenarios were based on combining the following scenarios:

- Lower bound scenario = 1a + 2a + 4a
- Upper bound scenario = 1b + 2b + 4b

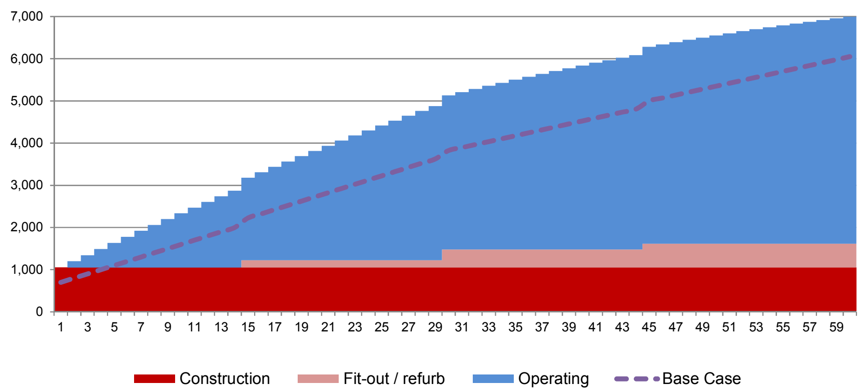
The results are shown in Figure E.8.

LOWER: low embodied, low operating, best case decarb



	$kgCO_2e/m^2$	%
Initial construction	470	19%
Fit-out and refurb	218	9%
Operating energy	1,830	73%
TOTAL	**2,519**	
Change compared to base case		*-58%*

UPPER: high embodied, high operating, slow to act decarb



	$kgCO_2e/m^2$	%
Initial construction	1,050	15%
Fit-out and refurb	569	8%
Operating energy	5,376	77%
TOTAL	**6,995**	
Change compared to base case		*+16%*

Fig E.8 **60 year CO_2e emissions for upper and lower limit options**

E5.6 Annualised CO_2e emissions

Table E.4 shows the results from the previous scenarios annualised over the 60 year assessment period. This data was used in Figures 3.11 and 3.12 in Chapter 3.

	Initial construction	Fit-out and refurbishment	Operating energy	**Total**	% embodied	% initial construction	% initial to operating	% compared to base case	**Years of operating energy for initial ECO_2**
Base case	12	8	82	**101**	19%	12%	14%		**7**
1. Embodied energy									
a. Low ECO_2	8	5	82	**95**	14%	8%	10%	-6%	**10**
b. High ECO_2	18	11	82	**111**	26%	16%	21%	10%	**5**
2. Operating energy									
a. Low energy	12	8	55	**74**	26%	16%	21%	-27%	**5**
b. High energy	12	8	123	**142**	14%	8%	10%	40%	**11**
Rebuild after 30 years									
a. 30% less energy	24	4	81	**109**	26%	22%	30%	8%	**3**
b. 60% less energy	24	4	66	**94**	30%	25%	36%	-7%	**3**
Grid decarbonisation									
a. Best case	12	5	46	**62**	27%	19%	26%	-38%	**4**
b. Political reality?	12	6	60	**78**	23%	15%	20%	-23%	**5**
LOWER SCENARIO	8	4	31	**42**	27%	19%	26%	-58%	**4**
UPPER SCENARIO	18	9	90	**117**	23%	15%	20%	16%	**5**

Table E.4 Annualised operating and embodied CO_2e emissions for different scenarios

E6. FURTHER RESEARCH REQUIRED

There are still lots of issues requiring resolution and further research in relation to embodied carbon in buildings, including:

- Do embodied carbon emissions today have a bigger impact on climate change than operating energy emissions in the future?
- Who will produce and maintain a standard database of ECO_2 factors in each country?
- Is it possible to establish minimum embodied carbon benchmarks for rating tools and building regulations?
- Can embodied carbon be reliably used as an alternative to reducing operating carbon emissions in new buildings?
- How should carbon sequestration in timber be considered in assessments?

Notes

All websites were accessed on 6 May 2013 unless noted otherwise. Information papers referenced are available to download from www.wholecarbonfootprint.com.

1. The BSIRA Guide BG 10/2011 contains a summary of the key data plus case studies and an overview of issues pertaining to embodied carbon. The full inventory is an excel spreadsheet which will be available to download from a new website later in 2013.

2. Target Zero was a programme of work funded by Tata Steel (formerly Corus) and the British Construction Steelwork Association (BCSA) to provide guidance on the design and construction of sustainable, low and zero carbon buildings in the UK. Five building types were considered (office, school, warehouse, supermarket and mixed use) in the theoretical study. For each building type design options and costs were assessed and published in free guides available online, covering:
   - Operational energy (as calculated for building regulations purposes) and options to achieve a zero carbon design
   - Embodied carbon – steel frame v other options
   - BREEAM rating – very good, excellent and outstanding

   www.steelconstruction.info/Target_Zero.

3. Darby, H. *A review of currently available standards and software tools for assessing life cycle greenhouse gas emissions from buildings.* World Sustainable Building Conference 2011, Helsinki. Refer also to www.bsria.co.uk/news/rating-env-assessments accessed on 25 May 2012.

4. *How bad are bananas? The carbon footprint of everything* by Mike Berners-Lee, Profile Books, 2010. This book provides the carbon footprint of various things, from sending a text message (0.014 gCO_2e) to hosting a football world cup (2.8 million tCO_2e) and is a thought-provoking and entertaining read. The book also makes the point that it is almost impossible to spend £1 without increasing your carbon footprint – 'with wealth comes carbon responsibility'. The footprint varies depending on how you spend the £1: 160 gCO_2e on financial, legal or professional advice, 720 gCO_2e on a car, 930 gCO_2e on a typical supermarket trolley of food, 1.7 $kgCO_2e$ on petrol for your car, 4.6 $kgCO_2e$ on flights, 6 $kgCO_2e$ on the electricity bill and 10+ $kgCO_2e$ on budget flights. The carbon footprint is only negative if invested in active carbon reduction measures such as on well-executed rainforest preservation projects (-330 $kgCO_2e$) or renewable energy (-3 $kgCO_2e$ on solar panels).

5. Data taken from www.defra.gov.uk/statistics/environment/waste/wrfg09-condem/. A further 30 mt of waste was generated from excavation activities, of which 7.3 mt was used as aggregate and the rest sent to landfill or exempt sites. Refer also to the WRAP Halving Waste to Landfill website: www.wrap.org.uk/category/initiatives/halving-waste-landfill.

6. The European Committee for Standardisation Technical Committee 350 (CEN/TC 350) has developed standards for the sustainability of construction works and the calculation of the whole life performance of buildings, including EN 15978. Refer to Information Paper 13 – Embodied carbon standards for details.

7. The UK Climate Change Act (passed in November 2008) provides a legal framework for ensuring that the Government meets its commitments to tackle climate change. It requires that emissions are reduced by at least 80% by 2050 compared to 1990 levels, and introduces legally binding 5 yearly carbon budgets. The Committee on Climate Change (CCC), an independent body set up as part of the Act, monitors and reports back to Parliament annually on progress made in meeting the budgets. http://cccarchive.helpfulclients.com/carbon-budgets/path-to-2050/index.html.

8. The CCC recommends that the UK electricity grid needs to have a carbon intensity of around 50 gCO_2/kWh by 2030 to be compatible with legally binding carbon budgets. The UK Energy Bill, November 2012, provides incentives to deliver around 30% of electricity from renewables and also requires new coal power stations to have carbon capture to limit emissions to around 450 gCO_2/kWh when operating at base load.